FAME Mechanisms

Brian Whalen

NRL

202-404-2619

whalen@space.nrl.navy.mil

Steve Koss
NRL

202-767-0696

skoss@space.nrl.navy.mil

Mechanisms Subsystem

- Top Level Requirements
- Interstage-Spacecraft Separation System
  - Marmon Clamp
  - Kick-off Spring Canisters
- Trim Tab System
- Trim Area System
- Trim Mass System
- Backup Slides

Top Level Requirements

- **1st Priority: Maximize Reliability of Mechanism Design**
  - **Simplification / Redesign to Rigid Solar Array**
  - **Maximize Use of Heritage Hardware**
- **2nd Priority: Minimize Cost of Mechanism Design**
  - **Simplification / Redesign to Rigid Solar Array**
  - **Maximize Use of Heritage Hardware**
- **3rd Priority: Minimize Mass of Mechanism Design**
  - **Lightweighting Design Iteration Remains to Be Done**
    - **Potential for Weight Savings As Program Matures**

Top Level Requirements

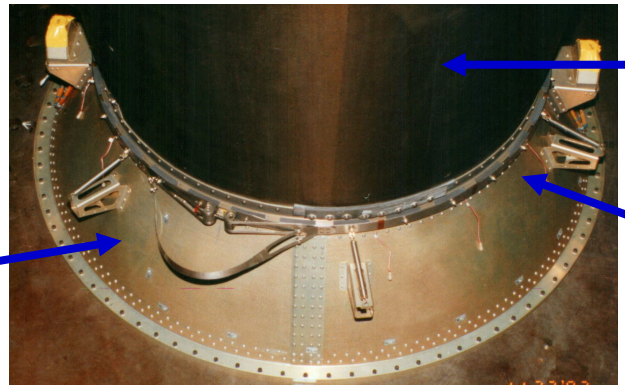
- **Interstage-Spacecraft Separation System**
  - **Provide a Highly Reliable Interstage-Spacecraft Separation System**
  - **Marmon Clamp**
    - **Structurally Hold Spacecraft to Interstage During Launch and Orbit Transfer Maneuvers**
  - **Kick-Off Spring Canisters**
    - **Provide a System and Interface That Will Separate the Spacecraft From the Interstage Cleanly (No Contact)**
    - **Assure No Re-Contact of Spacecraft to Interstage by Providing Minimum 3 inch/sec +/- 10% Delta V Between Vehicles**
- **Trim Tab System**
  - **Provide Three (3) Tabs Located 120° Apart Along the Circumference of the Electronics Deck to Provide a Solar Radiation Control Torque Range of +/- 1 Micro-N-m**
    - **Flowdown Requirement to Tab Sizing = a Minimum Area of 384 In^2**
    - **Flowdown Requirement to Tab Motion = One (1) DOF, Such That Upon Deployment, the Tab Pitches up and Down W.R.T. the Electronics Deck -40° to +40° in <0.5° Increments**

Top Level Requirements

- **Trim Area System**
  - **Provide Three (3) Pairs Located 120º Apart Along the Circumference of the Electronics Deck to Provide Center of Pressure Control Authority Within a 0.8-Inch Radius About the Spin Axis**
    - **Flowdown Requirement to Area Sizing = Trim Area Pair Area of 0-402 in^2**
    - **Flowdown Requirement to Area Motion = One (1) DOF, Such That Upon Deployment, the Areas Rotate in Plane of the Electronics Deck From 0° to 90° in <0.5° Increments**
- **Trim Mass System**
  - **Provide Two (2) Trim Mass Mechanisms Parallel to the Z-Axis to Adjust Ixz and Iyz**
  - **Size the Trim Mass Mechanisms Such That Ixz and Iyz Can Change Spin Axis Misalignment up to 30 Arcsec**
    - **Flowdown Requirement to Trim Mass Sizing = 2 Mechanisms With 6.5 lb Mass, +/- 9 Inch Travel in <0.004 in Step Increments**

Interstage Separation / Marmon Clamp

- ***Clementine* Flight Heritage Marmon Clamp Planned**
  - **At Satellite / Solid Rocket Separation Plane (Z=0 in)**
    - **FAME Required Preload = Pending Analysis – Should Be Less Than *Clementine* Qualification**
    - **Marmon Clamp Qualified to Preload of 3600 lb, Line Load N=240 lb/in**
    - **Thermal Conductance Test Planned to Refine Predicted Clamp Temps**
    - **If Temps Beyond Previous Qualifications Will Perform TVAC Delta Qual Test**



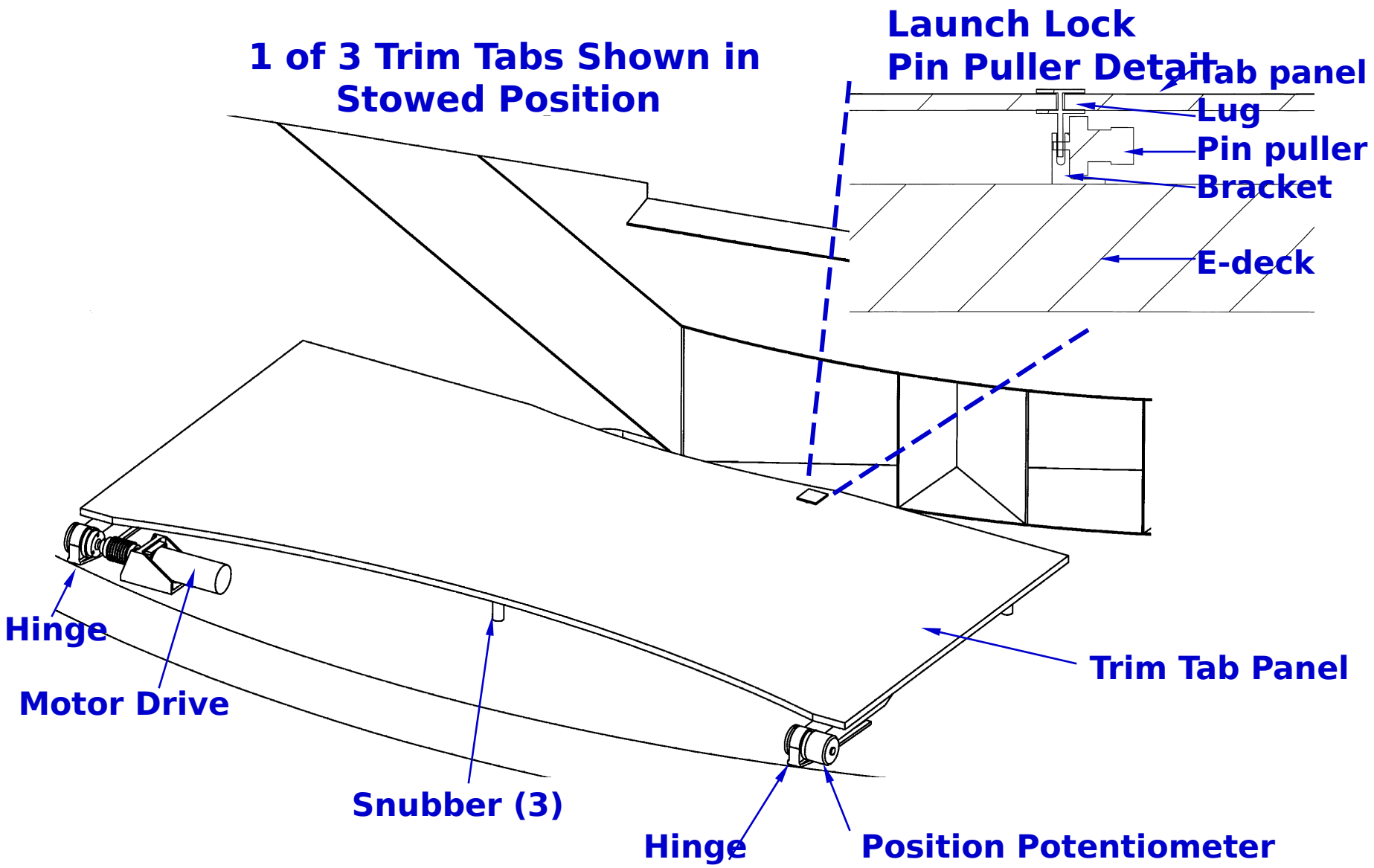
Clementine Marmon Clamp Shown

Interstage Separation / Kickoff Springs

- **TIPS Heritage Spring Cartridge Planned**

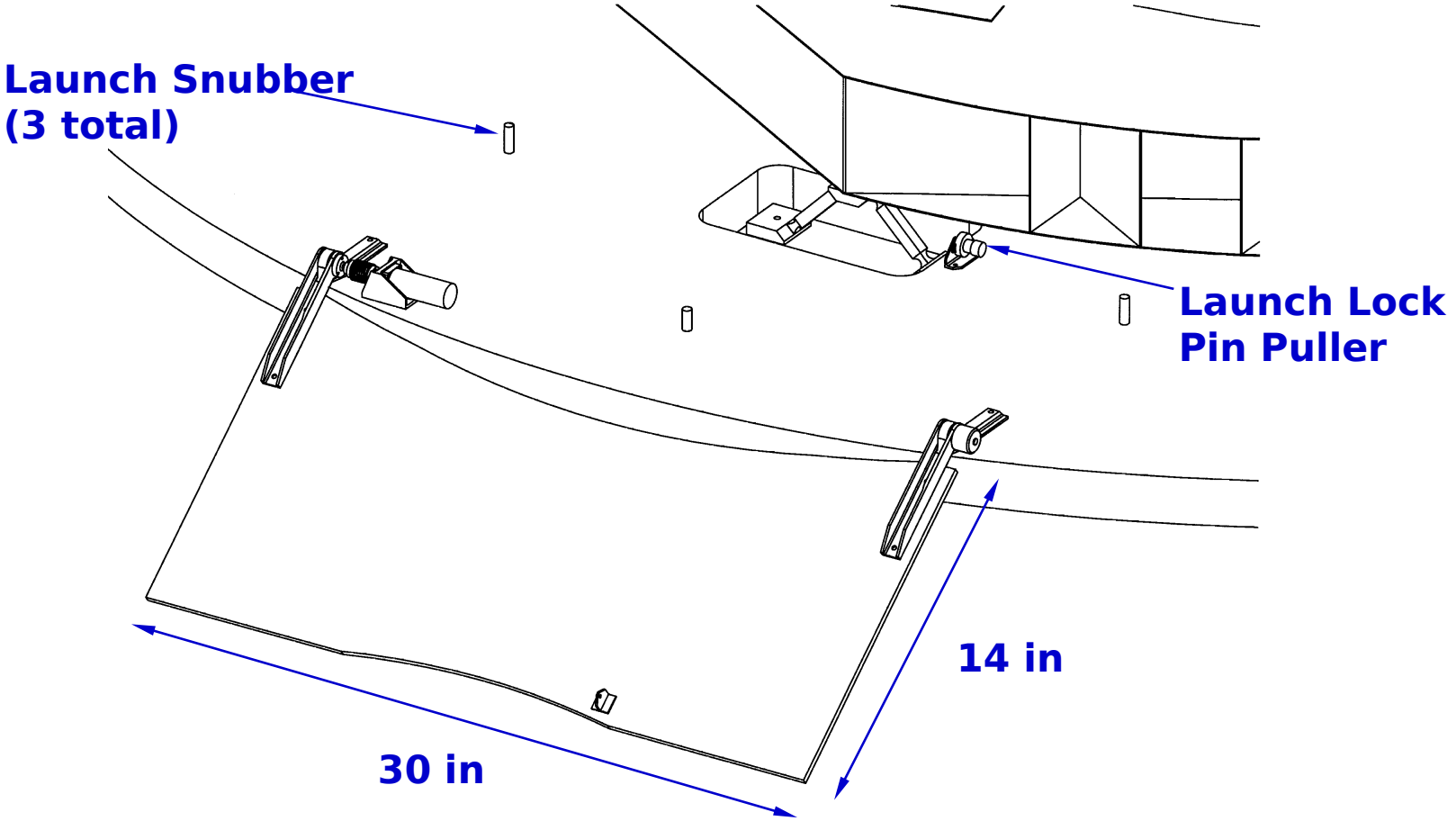
  HM-ME-0040
  - **Flight Heritage, No Design Changes**
  - **Use 64Around Interface**
  - **Same Spring: LC-125-6SS**
  - **Delta V = 3-5 inch/sec (Adjustable)**
  - **TBR May Need to Delta Qualify for Temperature or Other FAME Test Criteria**
  - **Weight: 0.50lb Each**
    - **4X = 2.0 lb**
  - **Size: 6.0in x 1.6in x 1.6in**
    - **Including Spring Force Adjustment Screw and Piston Retention Screw**
  - **Stroke: 1.0 in**

Trim Tabs (1 of 2)



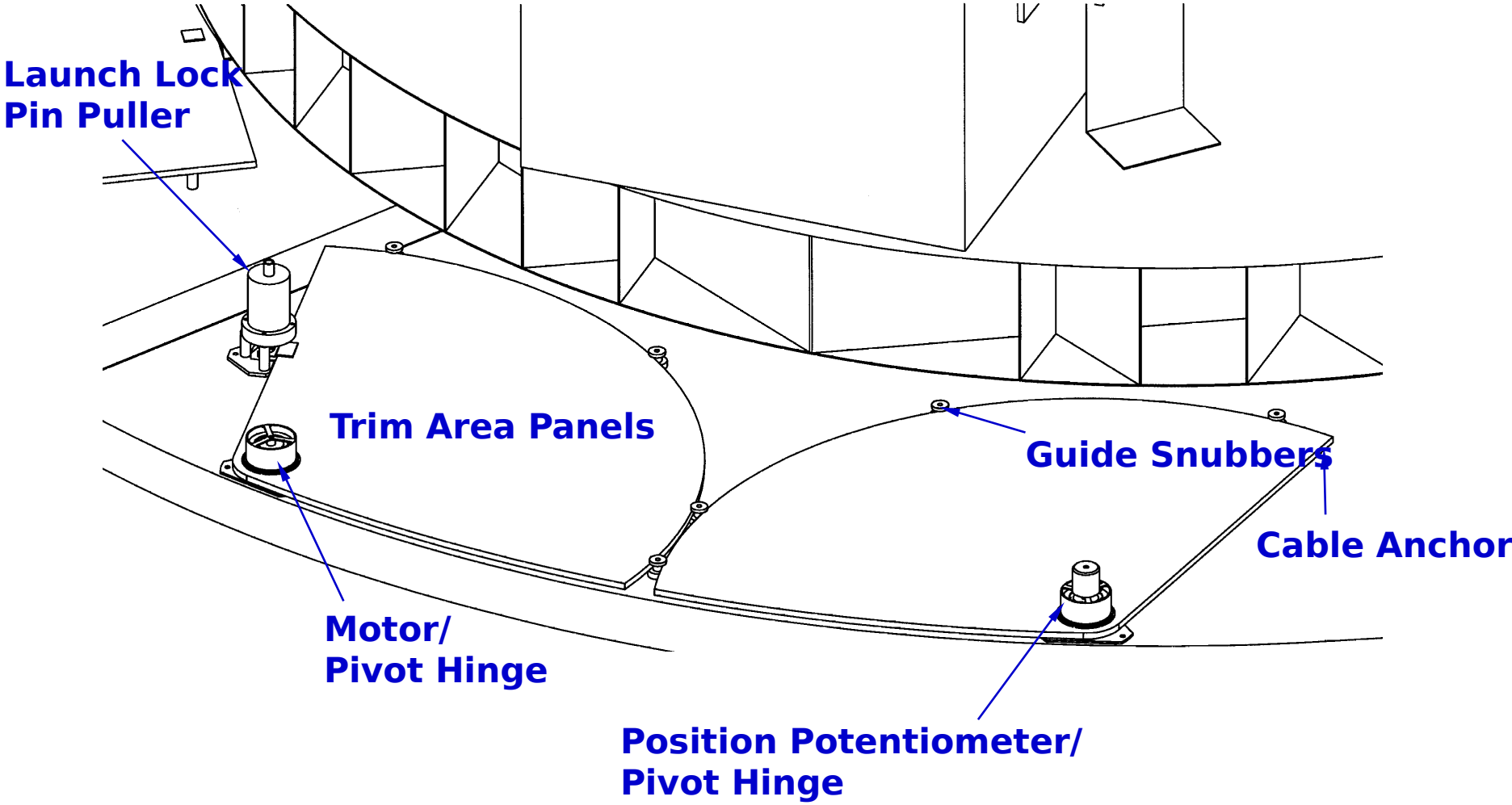
Trim Tabs (2 of 2)

1 of 3 Trim Tabs Shown in Deployed Position



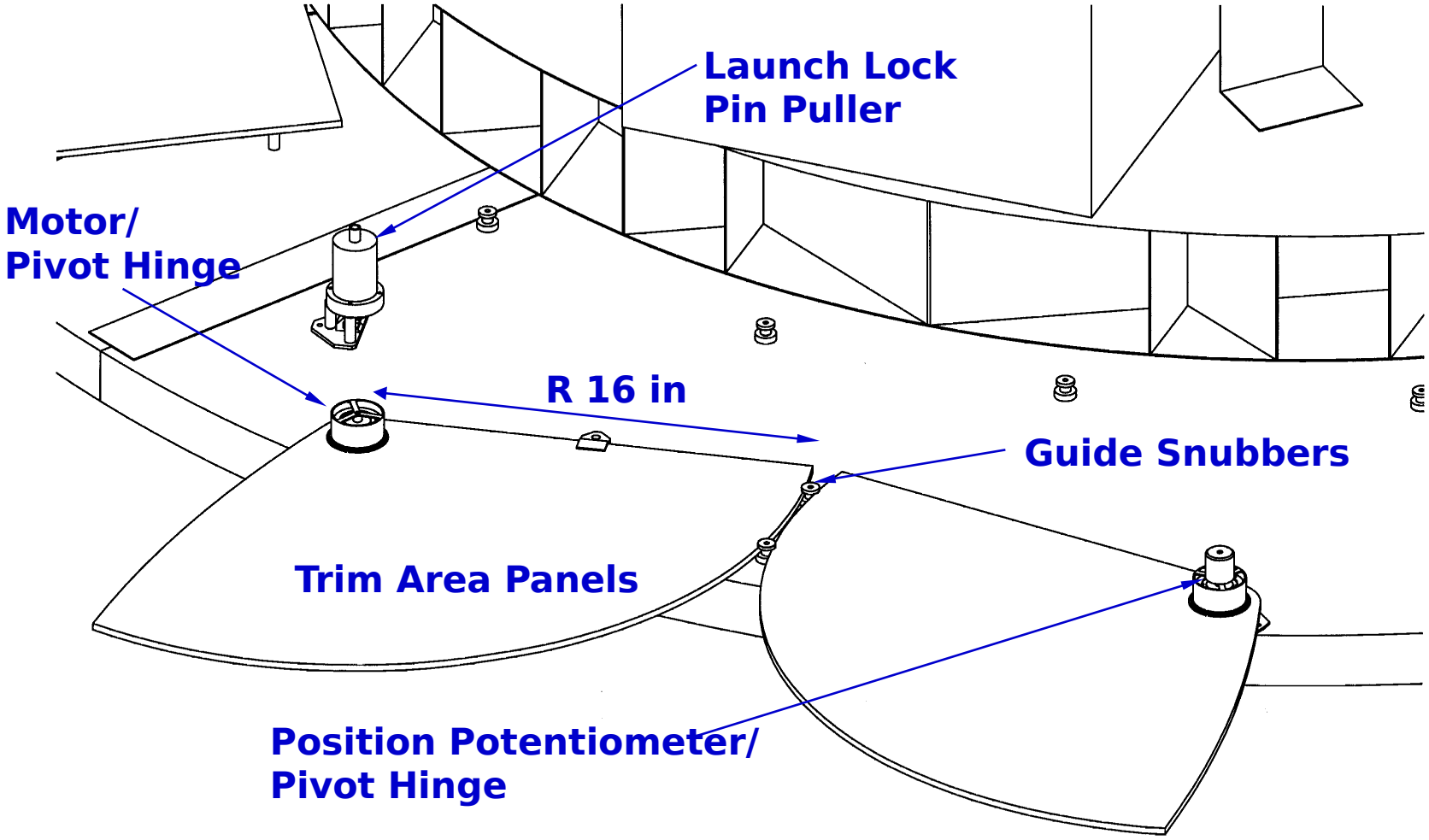
Trim Areas (1 of 2)

Cable Driven Trim Area Design
(1 of 3 Trim Area Pairs Shown in Stowed Position)



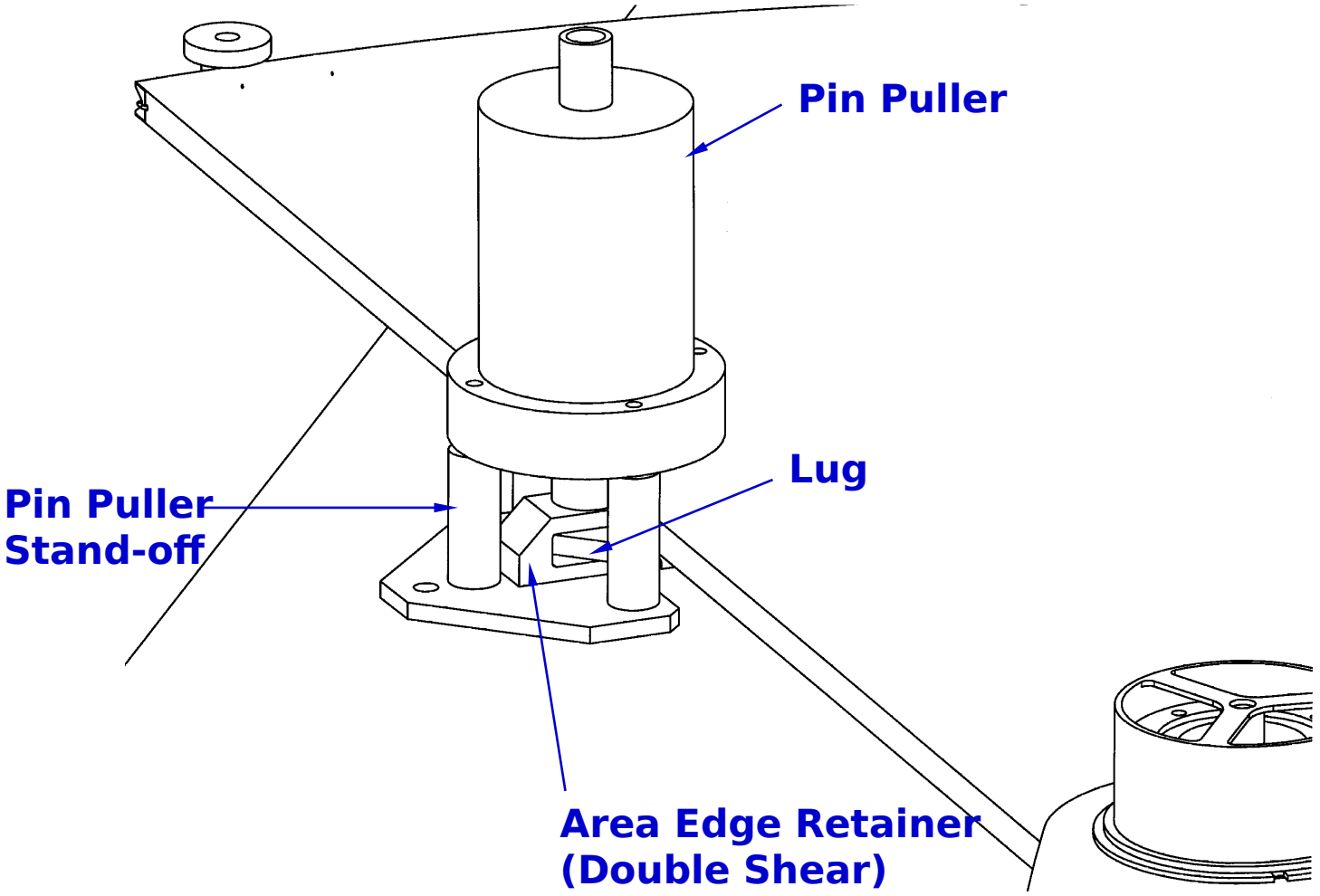
Trim Areas (2 of 2)

Cable Driven Trim Area Design
(1 of 3 Trim Area Pairs Shown in Fully Deployed Position)



Trim Areas (3 of 3)

Trim Area Pin Puller Launch Lock Detail

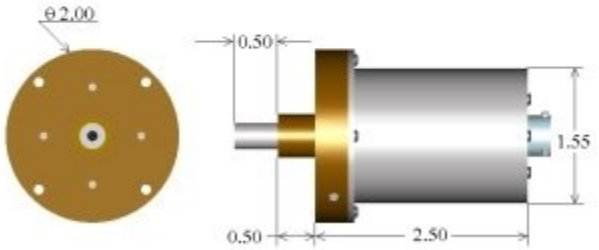


Trim Area / Trim Tab Pin Puller

Non-Explosive Pin Puller Launch Lock (Model P25-810-1.5R)

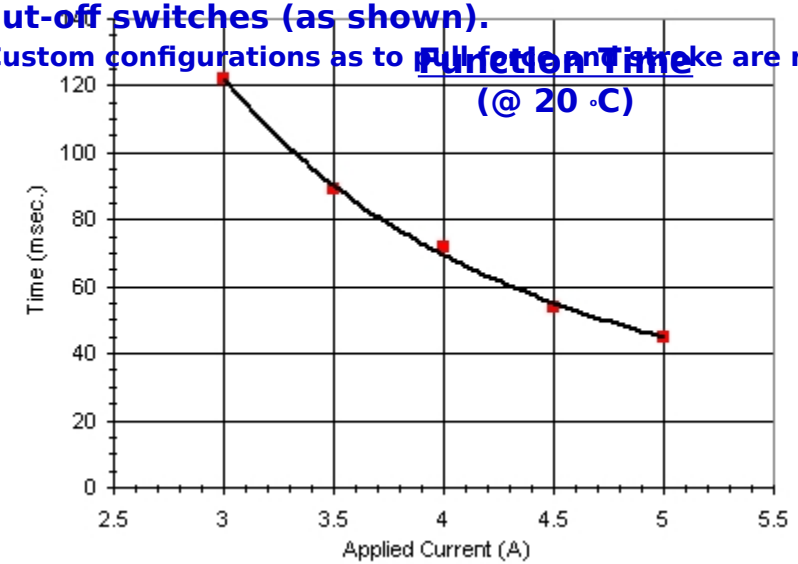
The Pinpuller model P25-810-1.5R was first used to deploy the ATEX (Advanced Research Experiment) built by the Naval Research Laboratory (NRL). This embodiment uses TiNi's patented trigger mechanism to retract the engagement pin with 25 lbs of force and 0.50" of stroke*. Fast actuation times are achieved by passing current directly through the Nitinol (Shape Memory Alloy) wire. The actuation time curve shown below is accurate for either of the two firing circuits incorporated. The fatigue life of the actuator is in the 100's of cycles allowing numerous pre-flight firings. Reset is achieved by manual re-extension of the pin. Optional additions that may be incorporated in the P25-810-1.5R are: custom mounting configurations, built in enclosure and connector, and integrated shut-off switches (as shown).

*** Custom configurations as to pull force and stroke are readily attainable.**



Dimensions shown in inches

Function Time (@ 20 ◦C)



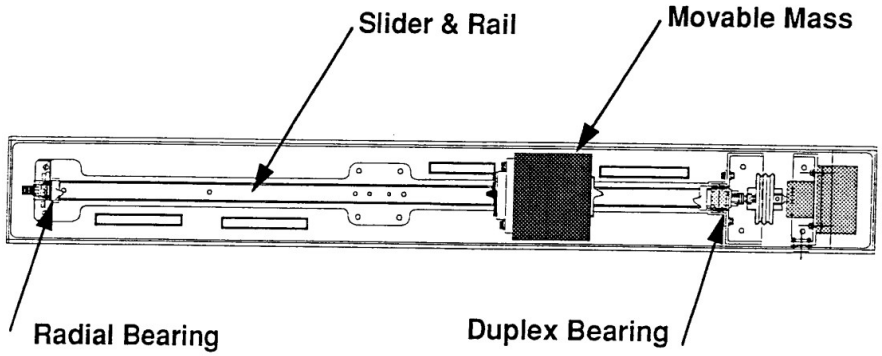
Specifications

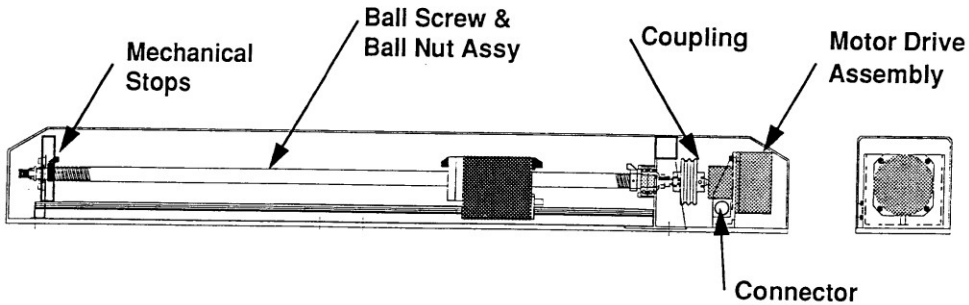
Pull Force	110 N	(25 lb-f)
Pull Stroke	1.27 cm	(0.5 in)
Operational Current	2 to 6 Amps	
Minimum Operating Temp.	<-50 °C	(<-58 °F)
Maximum Operating Temp.	+70 °C	(158 °F)
Actuator Resistance	1.2 Ohms	
Mass	110 gm	(0.25 lb)

Features:	Redundant SMA Circuit
	Reusable
	Auto Shut-Off Switch

Trim Masses

- **Design Layout Similar to Lockheed Martin Gravity Probe B Design**
- **FAME Trim Mass: 6.5 lb**
- **Stroke: +/- 9 in, Step Resolution: <0.1 mm**
- **Gravity Probe B Trim Mass: 20 lb**
- **Stroke: +/- 12 in, Step Resolution: 0.2mm**
- **Difference in FAME Mass/Stroke Requirements Dictates New NRL in-House Design - Design/Layout Similar to Gravity Probe B**
- **Will Prototype Early '02 to Reduce Development Risk**





Long Lead Items / Schedule

Mechanism Component	Cost	Purchase Delivery Date
• Marmon Clamp		
– Pyro Bolts, Pyros	$150K	Mar 02 — 26 Weeks
• Trim Tab		
– Motors	$160K	Jan 02 — 20 Weeks
– Pin Pullers	$30K	Jul 02 — 12 Weeks
• Trim Area		
– Motors	$125K	Jan 02 — 20 Weeks
– Pin Pullers	$30K	Jul 02 — 12 Weeks
• Trim Mass		
– Motors	$100K	Jan 02 — 20 Weeks
– ACME Screw, Nut & Rail		Under Investigation

Note: Cost Based on Vendor ROM Quotes

Note: Not All Necessary Hardware Is Listed

Summary

- **Mechanisms Design Utilizes Many Heritage Components**
- **Designs Which Are New Are Relatively Simple/Low Risk**
- **Internal/External Peer Review Held on 10/11/01**
  - **No Major Actions/Deficiencies Found**
- **Additional / Detailed Design Information Is Available Upon Request**
  - **Brian Whalen 202-404-2619 whalen@space.nrl.navy.mil**
  - **Steve Koss 202-767-0696 skoss@space.nrl.navy.mil**

Mechanisms Backup

Peer Review

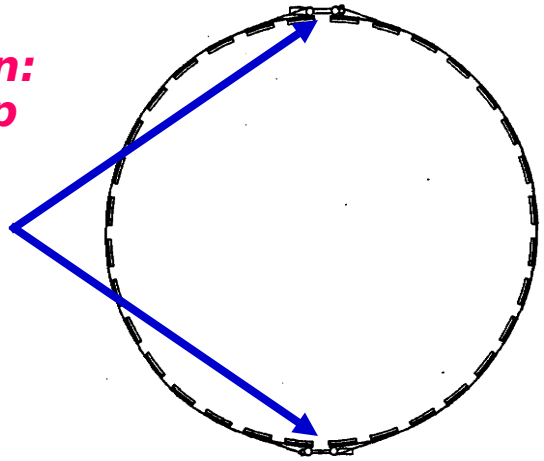
- **Internal/External Peer Review Held on 10/11/01**
  - **No Major Actions/Deficiencies Found**
  - **Actions/Suggestions:**
    - **Use Potentiometers for Position Feedback vs Cams & Microswitches**
    - **Revisit Motor Winding Redundancy vs $25K * 2lb Extra Electronics**
    - **Revisit Number of Microswitches for Telemetry on Trim Tabs/Areas/Masses**
    - **Add Subrequirement to Minimize Impact of Trim Area/Tab Movement on Dynamic Balance (Tolerances on Trim Tabs & Counterbalance Trim Area)**
    - **Consider Adding Center Position Indication Switch on Trim Masses**
    - **Consider Tapered Pins for Pin Pullers**
    - **Try to Use Single Guide Rail for Trim Mass to Reduce Tendency to Bind**
    - **Try to Lightweight Mechanisms in General, Especially Trim Tabs & Areas**
    - **Revisit Delta V Separation Requirements With Jim Barnds As Program Matures**
    - **Revisit # of Thermistors & Microswitches Used As Telemetry on Mechanisms**
    - **Get Better Traceability on Requirements Flowdown From Error Budget Document**
- **Attendees**
  - **Outside Reviewers: Ed Devine/Swales, Rodger Farley/NASA/GSFC, Joseph Bolek/NASA/GSFC, Alphonso Stewart/NASA/GSFC (Sent Slides to)**
  - **Various Internal NRL Personnel, Management, & Consultants Such as Russell Barnes, Bill Purdy**

Trades - Marmon Clamp

	Marmon Clamp	Separation Nuts (4, 6, or 8)		
		4	6	8
Load Path	Excellent (Cylinder-to-Cylinder)	Poor (Cylinder-to-Square)	Fair (Cylinder-to-Hexagon)	Fair (Cylinder-to-Octagon)
Weight	Good	Poor	Poor	Poor
Redundancy	Excellent	Good	Fair	Poor
Ordnance Required	Good (2-4)	Fair (8)	Fair (12)	Poor (16)

Selected Implementation: Marmon Clamp

Separation Devices in Two Places (Clamp Will Separate If Either or Both Devices Fire)



- Best Load Path (Cylinder to Cylinder)
- Significantly Lighter Than a 4 or 8 Separation Nut/Joint Systems
  - WRT Mechanisms Weight, Structure Weight, & Ordnance System Weight
- Reduces Required Ordnance From 16 Lines to 4 Lines (Maximum)
- Inherently Redundant

Trades - Kick-Off Spring Cartridge

- **ATEX Spring Cartridge**
  AX-ME-0026
  - Flight Heritage
  - Use 6 Around Interface
  - Change Spring to LC-135L-8SS
  - Delta V = 14.2 in/s (19% Margin)
  - Will Need to Delta Qualify With New Spring and Any Modified Parts
  - Weight: 0.45 Lb Each
    - 6 X = 2.4 lb
  - Size: 12 in X 2 in X 1.5 in
    Including Piston Retention Screw
  - Stroke: 2.5 in

- **TIPS Spring Cartridge**
  HM-ME-0045
  - Flight Heritage
  - Use 6 Around Interface
  - Same Spring: KH75034-3
  - Delta V = 14.2 in/s (18% Margin)
  - May Need to Delta Qualify for Temperature or Other FAME Test Criteria
  - Weight: 0.55 Lb Each
    - 6 X = 3.3 lb
  - Size: 9.9 in X 1.6 in X 1.6 in
    Including Spring Force Adjustment Screw and Piston Retention Screw
  - Stroke: 2.7 in

Note: Trade Open Until Design Finalized W.R.T. Access to Inside of Structur
Available Volume and Mass Constraints; Tips Has Been Baselined in

Trades - Trim Areas

Sector Gear

- Slightly Heavier (2 lb Al, 1 lb PEEK for 6 Sector Gears)
- Slightly More Hardware Costs
- Requires Backlash Compensation (TBR)
- Less Prone to Thermal Error
- More Robust Design and Predictable Behavior (TBR)

Cables

- Requires Higher Torque From Motor (Extra Motor Gearing)
- Slightly Lighter
- Slightly Less Hardware Cost
- TBD Position Accuracy/resolution
- More Prone to Thermal Errors (?)

Note: While Cables Have Been Baselined This Trade Remains Open Until Further Design Work Can Be Completed, Compatibility With Other Subsystems Is Established (ACS, Thermal); a Prototype of the Cable Design Will Be Built & Tested in Early '02

Trade Study - Trim Masses

New Trim Mass Design

- Optimized for FAME
- Lighter (Current Estimate =11.4 lb)
- Does Not Yet Have Contamination Cover
- Motion Verification Using Leadscrew Mounted Potentiometer and 3 Microswitches (Middle & Ends of Travel) for <.1 mm Linear Motion Resolution Verification

Lockheed MTM

- Overdesigned for FAME
- Heavy (40 lb As Is)
- Needs Significant Modification to Make Compatible With the FAME Requirements and Bus Design
- Should Be Used As a 'Lessons Learned' Example
- No Telemetry for Motion Verification

Selected Implementation: New Trim Mass Design
(A Prototype of the Trim Mass Mechanism Will Be Built & Tested in Early

Trade Study - Motors

- **Brushless vs Brush Trade**
  - **Brushless Chosen for Reliability Although Brush Motor @ Low Life Might Have Worked**
- **Type of Brushless Trade**
  - **Unipolar Stepper Chosen for Simplicity/Lowest Cost**
  - **Redundant Windings Chosen for Maximum Reliability**
    - **Electrical Redundancy Vs 30% Torque Penalty w/ Redundant Windings**
- **Vendor Trade**
  - **CDA Intercorp (Formerly Astro Instrument) Chosen Based on Good Previous Heritage W/NRL & On-Hand Qual Trim Mass Motor (ATEX Flight Spare)**
  - **Other Vendors' Reputations Are More Blemished or No Experience**

Trade Study – Position/Motion Verification

- None
  - Does Not Meet ACS Requirement to Verify Motion and Reduce Risk for Slow Spacecraft Reaction to Trim Mechanism Motion
- Potentiometers
  - Higher Hardware Costs
  - Have Troublesome History of Failures/Problems in Space/Vacuum
  - Fine Position Resolution
  - Absolute Position Capability for Trim Area & Trim Tabs
- Cams and Switches
  - Low Hardware Costs
  - Requires External Cam to Motor, Motor Change for Trim Tab
  - Cams Can All Be Made Identical
  - Coarser Position Resolution Than Potentiometers
  - Incremental Position Only
- Cams and Sensor
  - Hall Effect Sensor or LED/Diode Require More Electronics

Selected Implementation: Potentiometers With End of Travel Swi

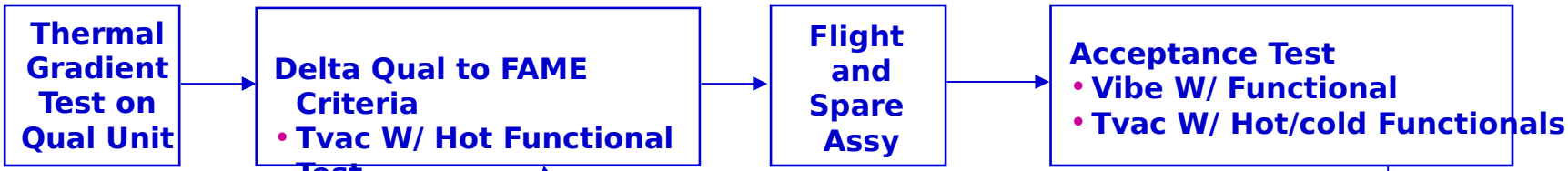
Trade Study - Pin Pullers

- 25 Lb TiNi Pin Puller
  - Higher Margin on Loads
  - Larger Size, Weight (.25 lb)
  - Qualified on WindSat Program, in-House Knowledge of Mechanism
  - Resettable
- 5 Lb TiNi Pin Puller
  - Low Margins on Loads
  - Compact and Lightweight (0.5 oz)
  - No in-House Knowledge of Design
  - Resettable
- Pyro Pin Puller
  - High Margins
  - Compact and Lightweight
  - Not Resettable
  - Safety Issues
- Paraffin Pin Puller
  - High Margins
  - Compact, but 2 X Weight of TiNi Pin Puller
  - Resettable

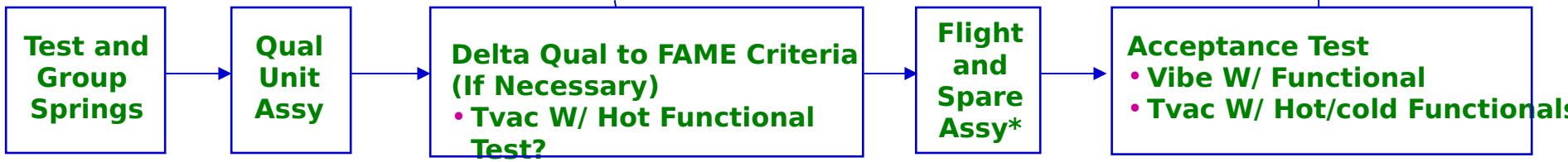
Selected Implementation: 25 lb TiNi pin puller

Test Flow
IS/SC Separation System

Marmon Clamp

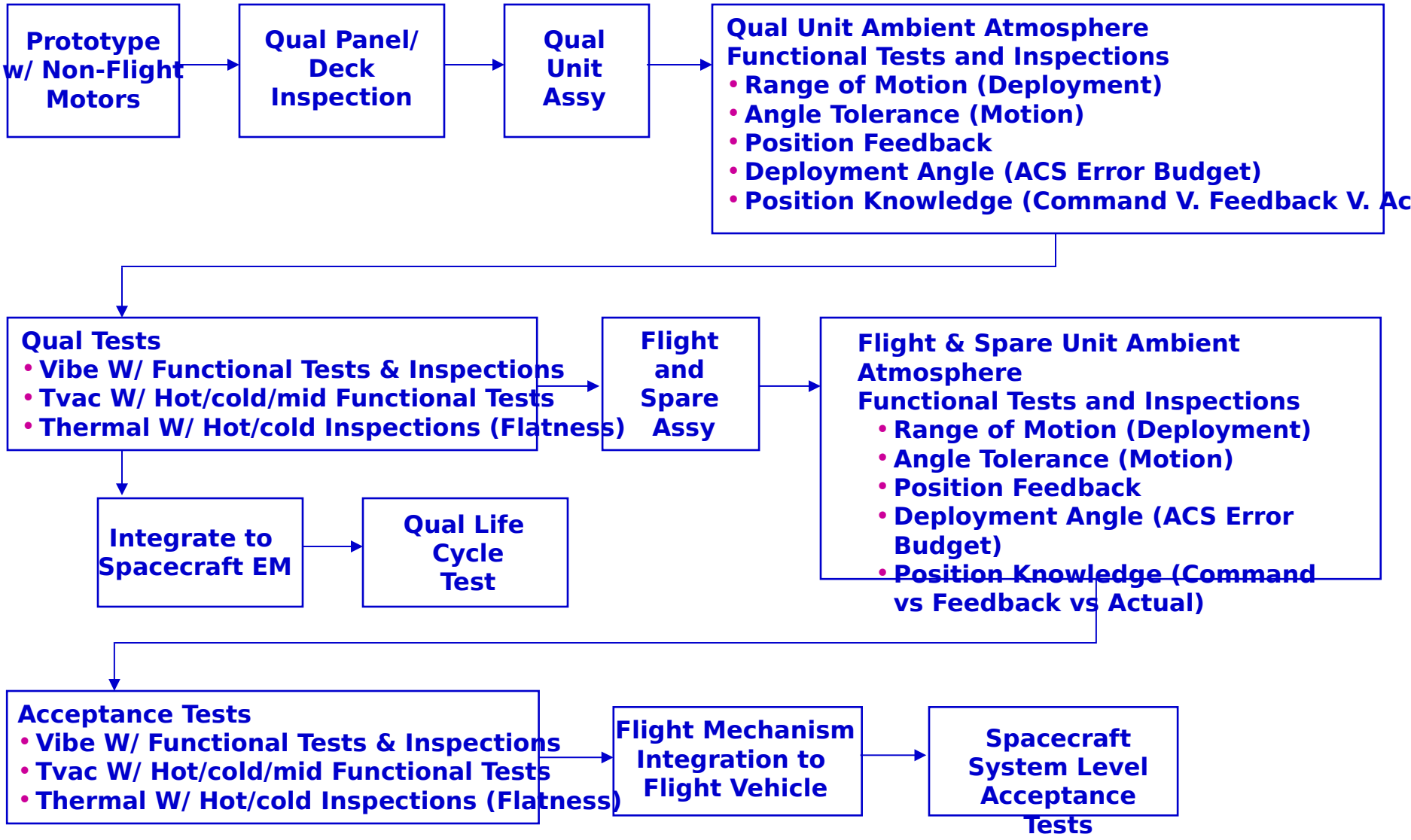


Spring Cartridge



* May Be Able to Use Qual Spring Cartridge Units As Flight or Spare

Test Flow
Trim Tabs and Trim Areas



Test Flow
Trim Masses